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Saito et al.

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(54) **WIRELESS COMMUNICATION APPARATUS AND TRANSMISSION POWER CONTROL METHOD**

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H04L 27/36 (2006.01)
(Continued)

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CPC ***H04L 27/362*** (2013.01); ***H03G 3/3042*** (2013.01); ***H04L 27/3405*** (2013.01); *Y02B 60/50* (2013.01)

(58) **Field of Classification Search**
CPC H04B 2001/0416; H03G 3/3047; H03G 3/001; H03G 3/20; H03G 3/301; H03G 1/02
USPC 375/295, 296, 297; 330/278, 282; 455/127.1, 127.2
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,291,410 A * 9/1981 Caples et al. 375/345
5,732,334 A * 3/1998 Miyake 455/126
(Continued)

FOREIGN PATENT DOCUMENTS

JP 08-265210 A 10/1996
JP 2001-086010 A 3/2001
(Continued)

OTHER PUBLICATIONS

International Search Report for Application No. PCT/JP2013/007659 dated Apr. 8, 2014.

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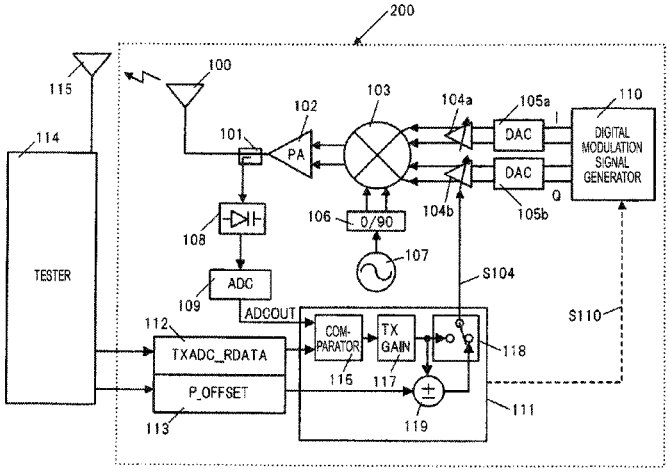
(74) *Attorney, Agent, or Firm* — Pearne & Gordon LLP

(57) **ABSTRACT**

A variable gain amplifier amplifies a baseband signal. A quadrature modulator quadrature-modulates the amplified baseband signal to generate a high-frequency signal. A power amplifier amplifies the generated high-frequency signal. An antenna transmits the amplified high-frequency signal. A detector detects the amplified high-frequency signal. A first nonvolatile memory stores the desired transmission power of the high-frequency signal to be transmitted from the antenna. A controller adjusts the gain of the variable gain amplifier depending on the output of the detector and the transmission power stored in the first nonvolatile memory.

3 Claims, 7 Drawing Sheets



(51) **Int. Cl.**

H03G 3/30	(2006.01)
H04L 27/34	(2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,292,120	B1 *	9/2001	Painchaud et al.	341/139
6,591,089	B1	7/2003	Ichihara	
6,721,368	B1	4/2004	Younis et al.	
7,808,322	B1 *	10/2010	Son et al.	330/278
8,085,869	B2 *	12/2011	Behzad	375/297
2010/0027596	A1 *	2/2010	Bellaouar et al.	375/219

FOREIGN PATENT DOCUMENTS

JP	2008-245058	A	10/2008
JP	2009-044470	A	2/2009
JP	2010-021747	A	1/2010
JP	2012-016027	A	1/2012

* cited by examiner

FIG. 1

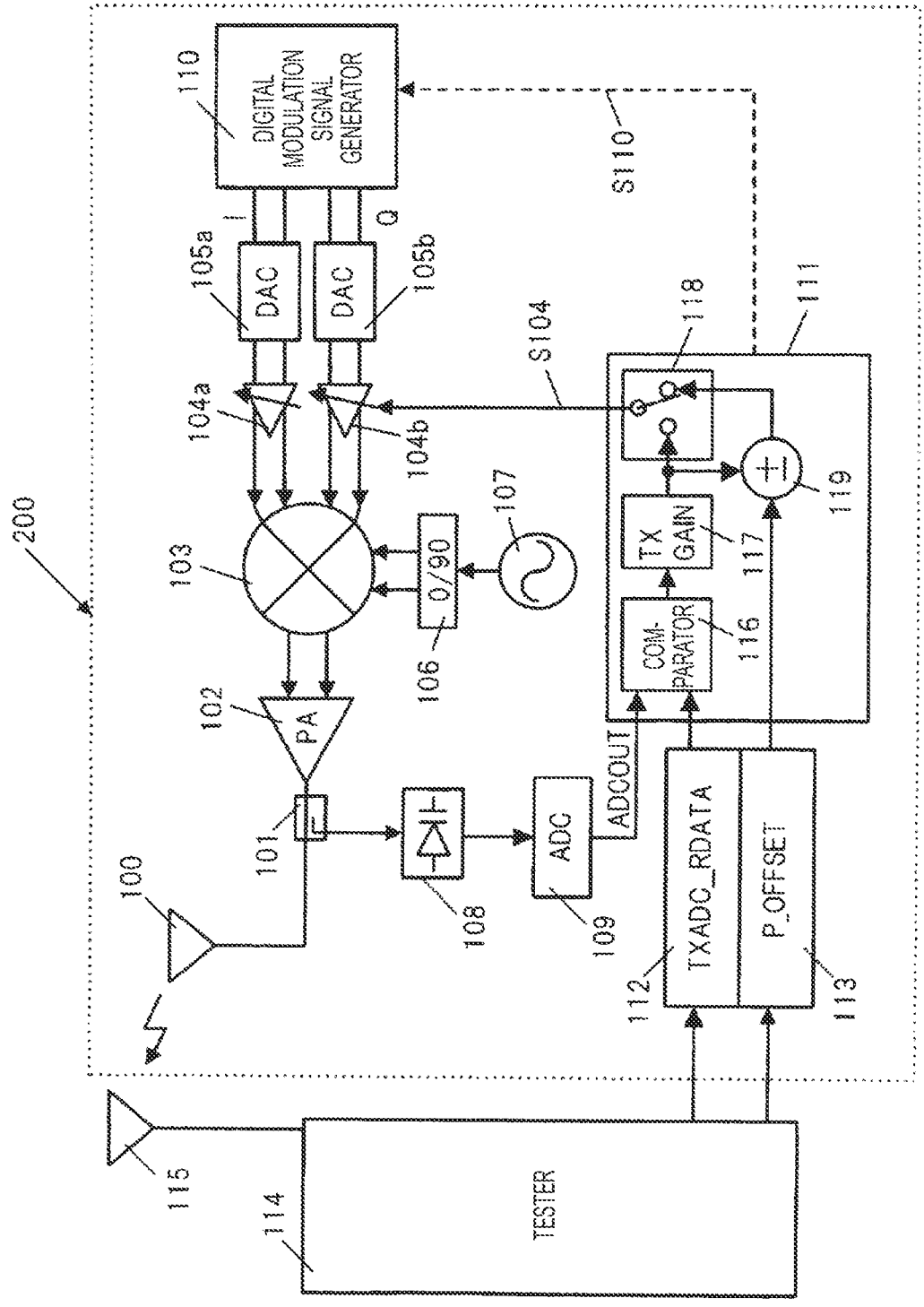

200
110
DIGITAL MODULATION SIGNAL GENERATOR
S110
I
Q
105a
DAC
105b
DAC
104a
104b
S104
118
111
103
0/90
106
107
TX GAIN
117
119
COM-PARATOR
116
102
PA
101
108
ADC
109
ADCOUT
100
112
TXADC_RDATA
P_OFFSET
113
115
114
TESTER

FIG. 2

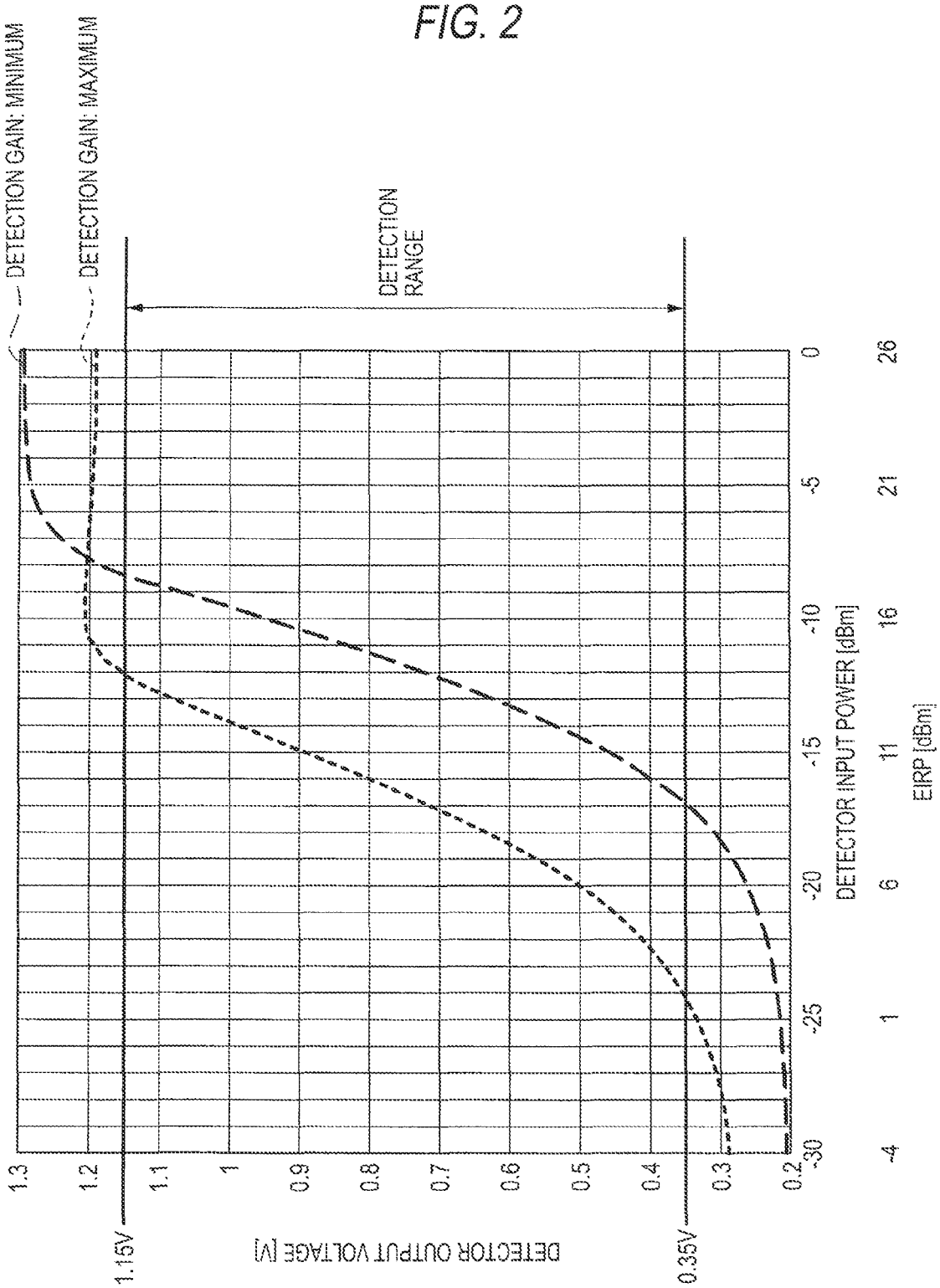

DETECTION GAIN: MINIMUM
DETECTION GAIN: MAXIMUM
DETECTION RANGE
1.15V
0.35V
DETECTOR OUTPUT VOLTAGE [V]
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
DETECTOR INPUT POWER [dBm]
0
-5
-10
-15
-20
-25
-30
EIRP [dBm]
26
21
16
11
6
1
-4

FIG. 3

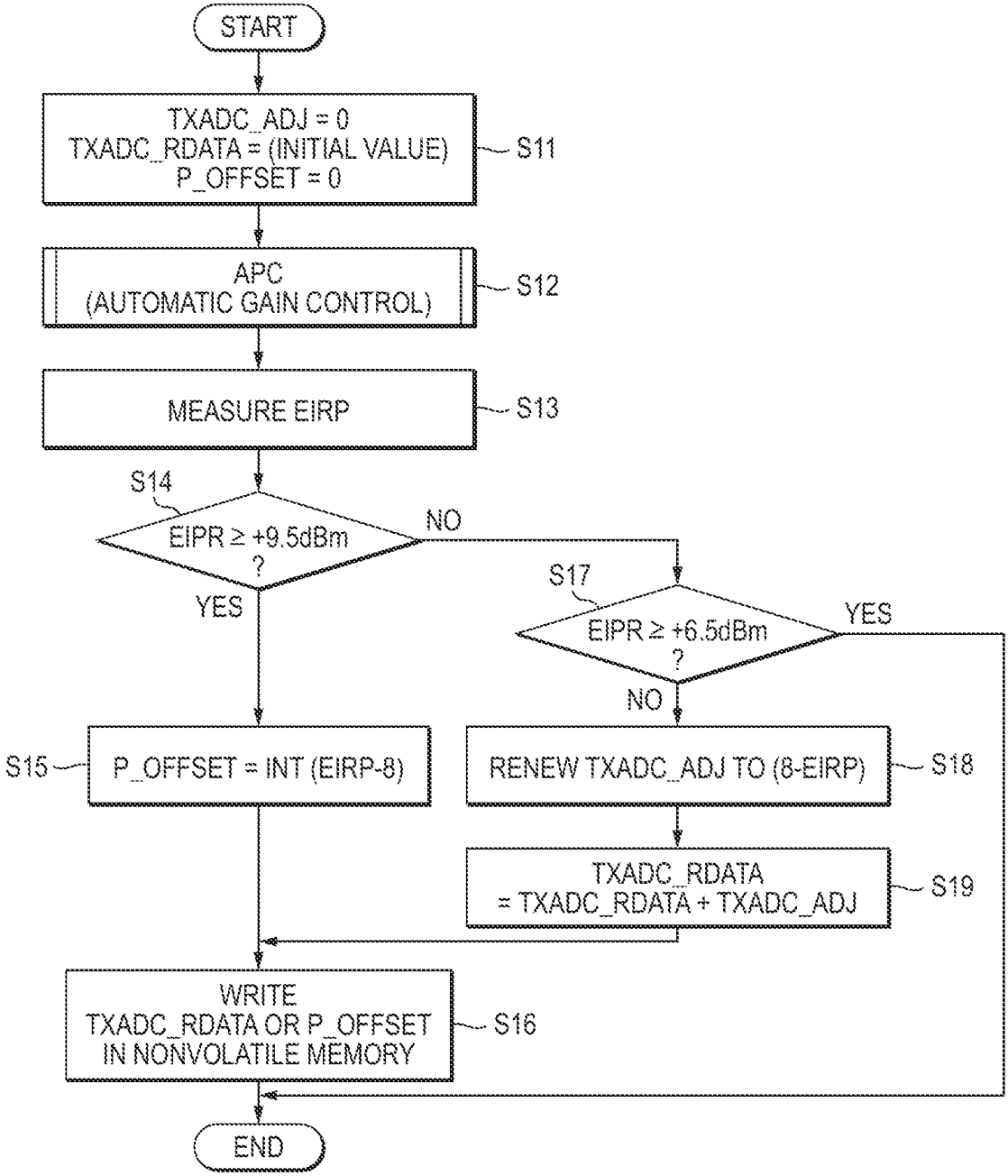

START
TXADC_ADJ = 0
TXADC_RDATA = (INITIAL VALUE)
P_OFFSET = 0
S11
APC
(AUTOMATIC GAIN CONTROL)
S12
MEASURE EIRP
S13
S14
EIPR ≥ +9.5dBm ?
NO
YES
S17
EIPR ≥ +6.5dBm ?
YES
NO
S15
P_OFFSET = INT (EIRP-8)
RENEW TXADC_ADJ TO (8-EIRP)
S18
TXADC_RDATA
= TXADC_RDATA + TXADC_ADJ
S19
WRITE
TXADC_RDATA OR P_OFFSET
IN NONVOLATILE MEMORY
S16
END

FIG. 4

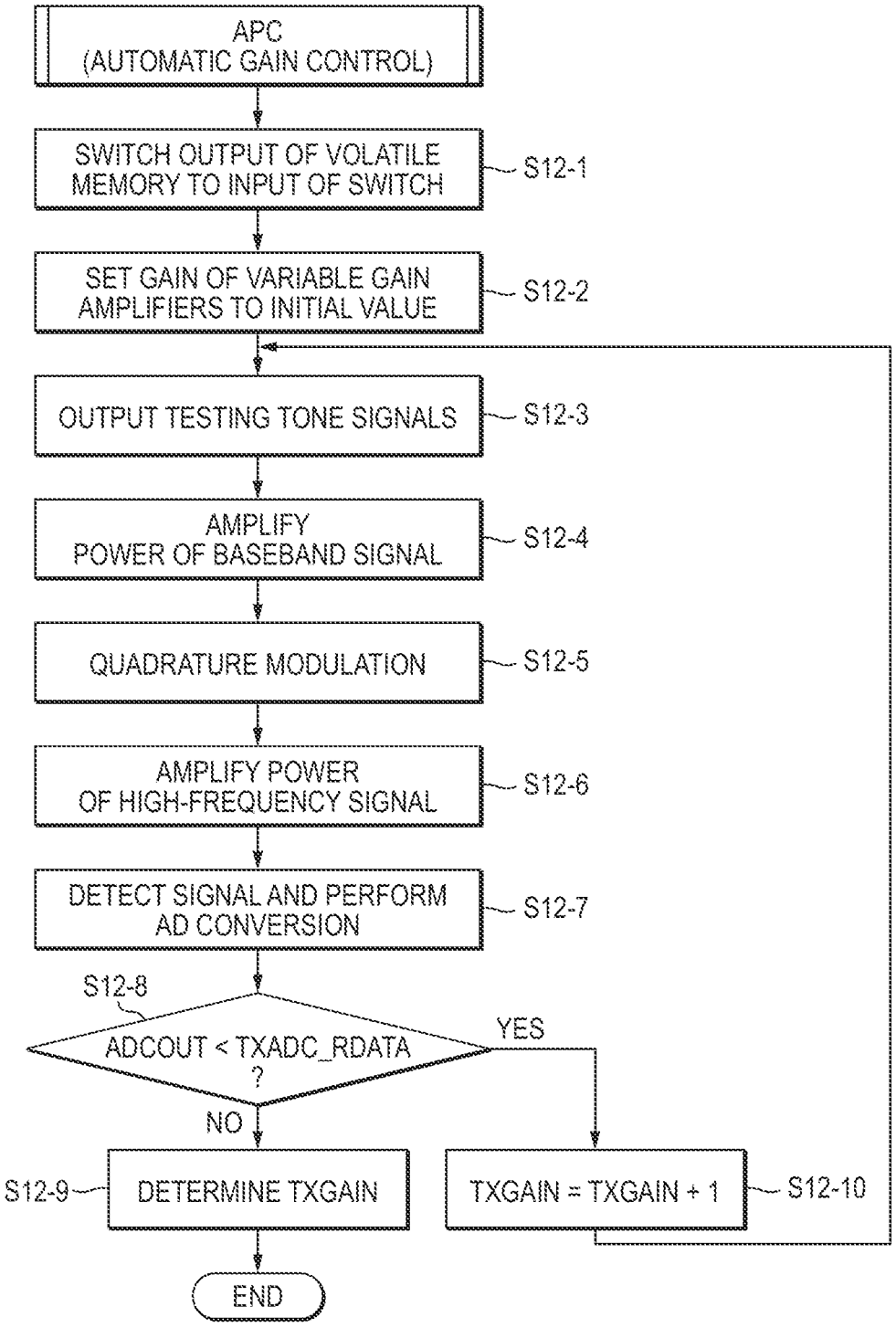

APC
(AUTOMATIC GAIN CONTROL)
SWITCH OUTPUT OF VOLATILE MEMORY TO INPUT OF SWITCH
S12-1
SET GAIN OF VARIABLE GAIN AMPLIFIERS TO INITIAL VALUE
S12-2
OUTPUT TESTING TONE SIGNALS
S12-3
AMPLIFY POWER OF BASEBAND SIGNAL
S12-4
QUADRATURE MODULATION
S12-5
AMPLIFY POWER OF HIGH-FREQUENCY SIGNAL
S12-6
DETECT SIGNAL AND PERFORM AD CONVERSION
S12-7
S12-8
ADCOUT < TXADC_RDATA ?
YES
NO
S12-9
DETERMINE TXGAIN
TXGAIN = TXGAIN + 1
S12-10
END

FIG. 5

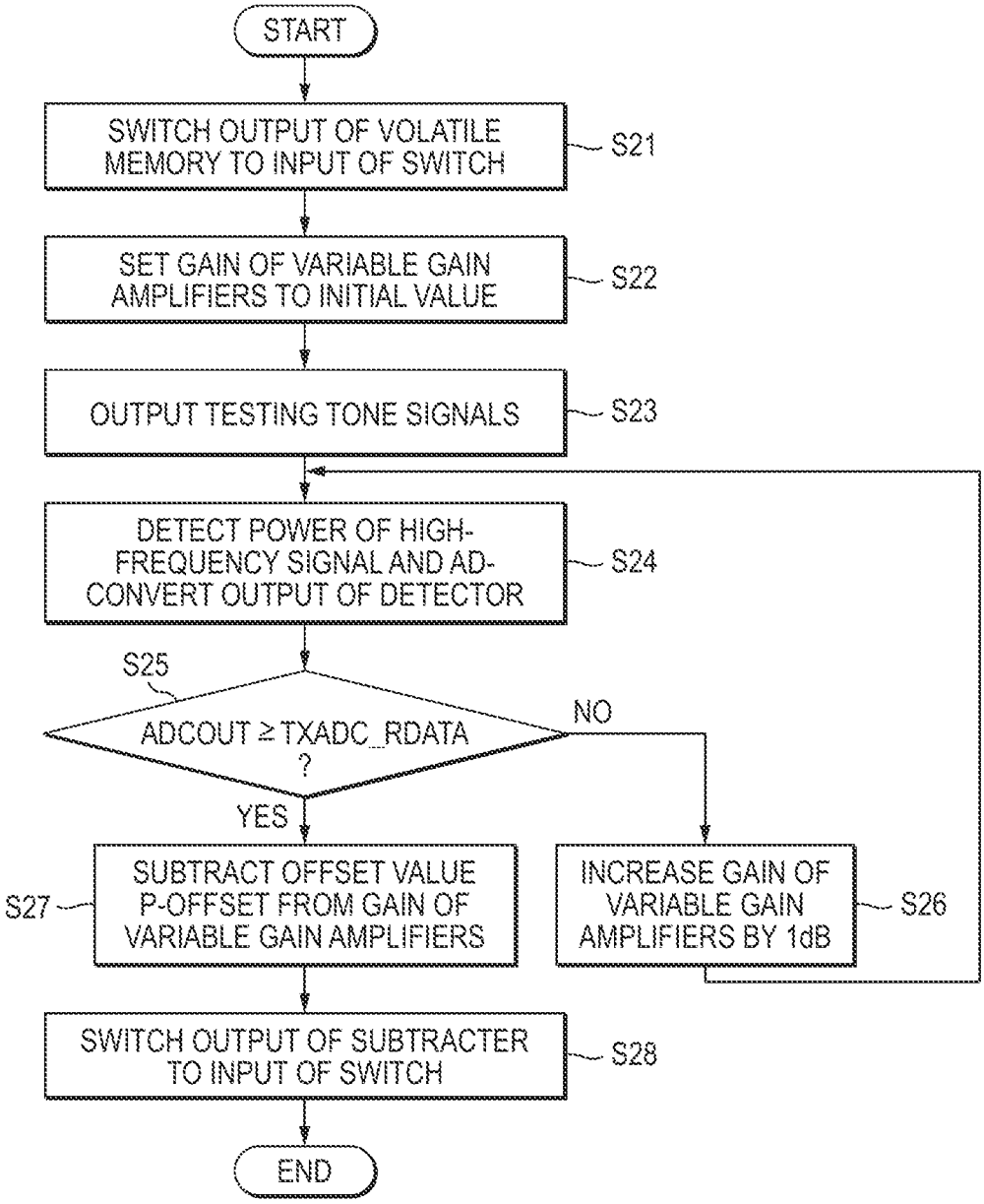

START
SWITCH OUTPUT OF VOLATILE MEMORY TO INPUT OF SWITCH
S21
SET GAIN OF VARIABLE GAIN AMPLIFIERS TO INITIAL VALUE
S22
OUTPUT TESTING TONE SIGNALS
S23
DETECT POWER OF HIGH-FREQUENCY SIGNAL AND AD-CONVERT OUTPUT OF DETECTOR
S24
S25
ADCOUT ≥ TXADC_RDATA ?
NO
YES
SUBTRACT OFFSET VALUE P-OFFSET FROM GAIN OF VARIABLE GAIN AMPLIFIERS
S27
INCREASE GAIN OF VARIABLE GAIN AMPLIFIERS BY 1dB
S26
SWITCH OUTPUT OF SUBTRACTER TO INPUT OF SWITCH
S28
END

FIG. 6

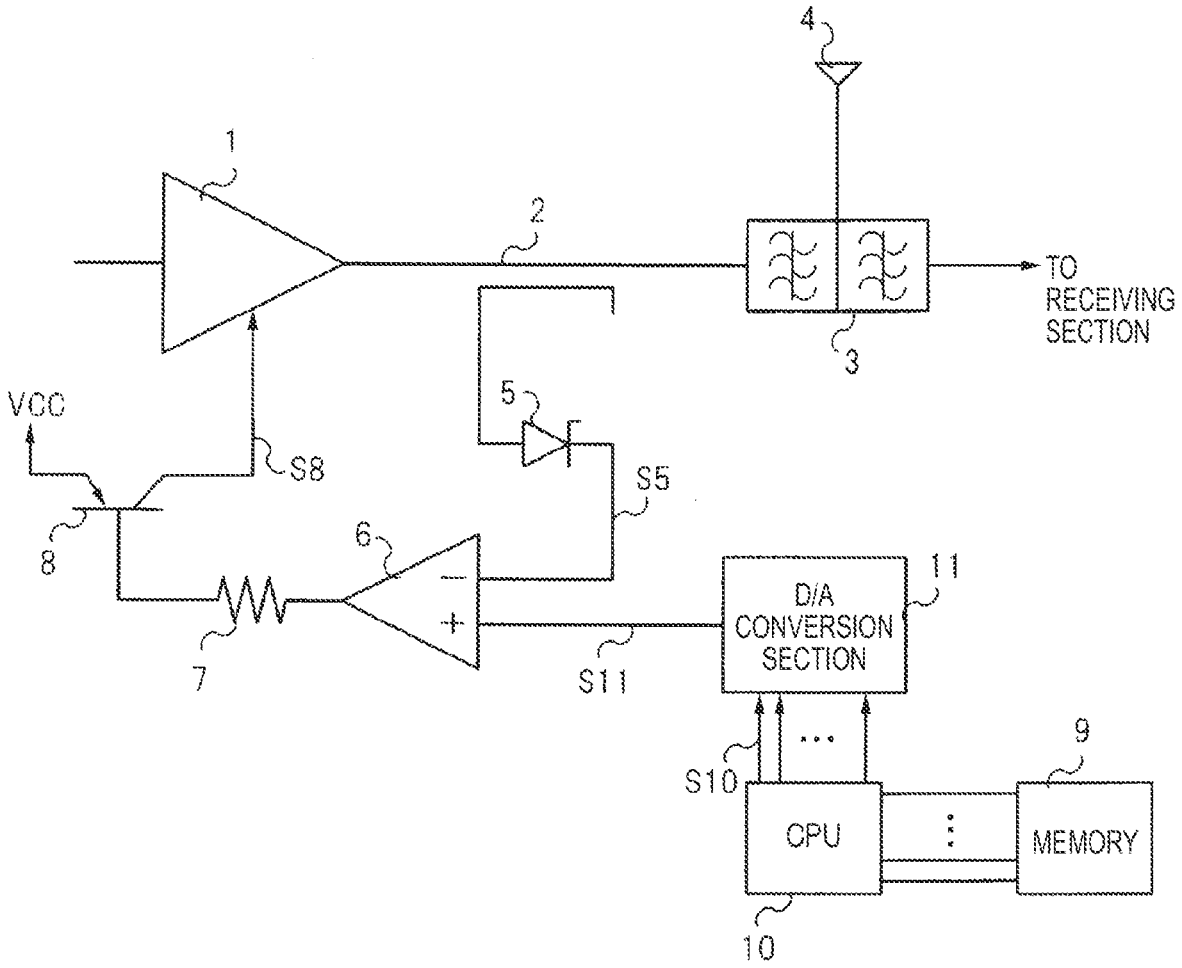
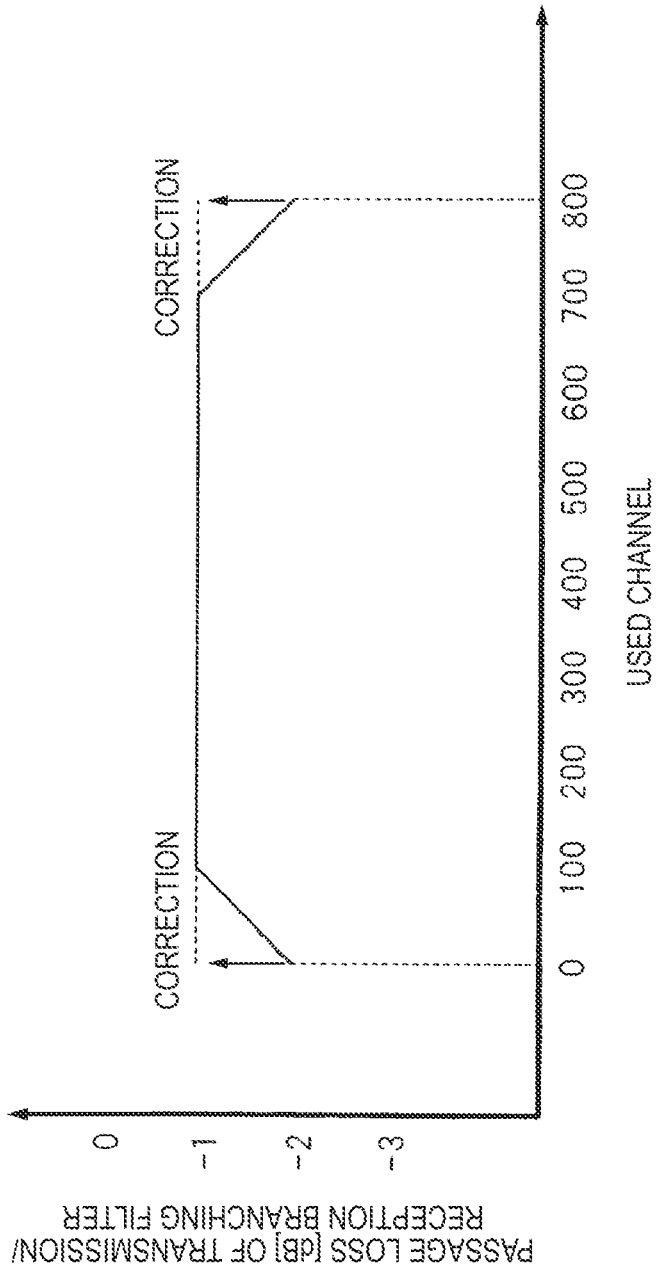

4
1
2
TO
RECEIVING
SECTION
3
5
VCC
S8
S5
8
6
7
S11
D/A
CONVERSION
SECTION
11
S10
9
CPU
MEMORY
10

FIG. 7


CORRECTION
CORRECTION
0
100
200
300
400
500
600
700
800
USED CHANNEL
0
-1
-2
-3
PASSAGE LOSS [dB] OF TRANSMISSION/
RECEPTION BRANCHING FILTER

WIRELESS COMMUNICATION APPARATUS AND TRANSMISSION POWER CONTROL METHOD

TECHNICAL FIELD

The present disclosure relates to a wireless communication apparatus and a transmission power control method for controlling the transmission power of a high-frequency signal.

In recent years, as the micro-fabrication technology in CMOS (Complementary Metal Oxide Semiconductor) processes advances, integrated circuits for millimeter wave wireless communication using, for example, a 60 GHz band, have been put into practical use. The operating frequency of such an integrated circuit for millimeter wave band wireless communication is higher than the operating frequency of an integrated circuit for microwave band wireless communication, thereby becoming the high cutoff frequency ft in a CMOS process; in other words, the current gain becomes one time; hence, the difference between the frequency at which the integrated circuit is difficult to be used as an amplifying element and the operating frequency thereof decreases, whereby the two frequencies are close to each other.

For this reason, the gain of an amplifier for high-frequency signals varies significantly due to variation in a CMOS process and temperature change. Furthermore, since variation in antenna gain is apt to occur in millimeter wave band wireless communication, there has been a problem that the EIRP (Effective Isotropic Radiated Power) of an antenna in a wireless communication apparatus is apt to vary.

To solve this problem, a wireless communication apparatus for correcting the deviation of transmission power due to variation in the process using a nonvolatile memory has been known conventionally (for example, refer to Patent Document 1). The operation of the wireless communication apparatus disclosed in Patent Document 1 will be described later referring to FIGS. **6** and **7**.

PRIOR ART DOCUMENT

Patent Document

Patent Document 1: JP-A-8-265210

SUMMARY OF THE INVENTION

Problem That the Invention Is to Solve

However, in Patent Document 1, in the case that variation occurs in antenna gain, correcting the power of a high-frequency signal is not considered. For this reason, in wireless communication (for example, millimeter wave wireless communication) in which variation is apt to occur in antenna gain, there occurs a problem that it is difficult to make the EIRP of the antenna in the wireless communication apparatus constant.

In order to solve the above-mentioned conventional problem, the present disclosure is intended to provide a wireless communication apparatus and a transmission power control method for making the EIRP of an antenna constant even if variation occurs in antenna gain in wireless communication dealing with high-frequency signals.

Means for Solving the Problem

The present disclosure provides a wireless communication apparatus equipped with a variable gain amplifier that amplifies a baseband signal; a quadrature modulator that quadrature-modulates the amplified baseband signal to generate a high-frequency signal; a power amplifier that amplifies the generated high-frequency signal; an antenna that transmits the amplified high-frequency signal; a detector that detects the amplified high-frequency signal; a first nonvolatile memory that stores the desired transmission power of the high-frequency signal to be transmitted from the antenna; and a controller that adjusts the gain of the variable gain amplifier depending on the output of the detector and the transmission power stored in the first nonvolatile memory.

In addition, the present disclosure provides a transmission power control method for use in a wireless communication apparatus for transmitting a high-frequency signal from an antenna and in a tester for testing the transmission power of the high-frequency signal transmitted from the antenna, wherein the wireless communication apparatus has a first nonvolatile memory for storing the initial value of the transmission power of the high-frequency signal to be transmitted from the antenna and a second nonvolatile memory, and the tester stores the desired range of the transmission power of the high-frequency signal to be transmitted from the antenna, adjusts the gain of variable gain amplifiers so that the output of the tester is equal to the transmission power stored in the first nonvolatile memory, and then, in the case that the transmission power of the high-frequency signal transmitted from the antenna is larger than an upper limit value in the desired range of the transmission power, writes a difference between the transmission power of the high-frequency signal and a predetermined value in the desired range of the transmission power in the second nonvolatile memory.

Advantage of the Invention

With the present disclosure, in wireless communication dealing with high-frequency signals, the EIRP of an antenna can be made constant even if the gain of the antenna varies.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing the configuration of a wireless communication apparatus according to this embodiment;

FIG. **2** is a graph showing the relationship between the input power and the output voltage in the case of the detector having the minimum detection gain and in the case of the detector having the maximum detection gain;

FIG. **3** is a flow chart illustrating the operation procedure for writing data in the first and second nonvolatile memories of the wireless communication apparatus according to this embodiment;

FIG. **4** is a flow chart illustrating the operation procedure of the APC (automatic gain control) of the wireless communication apparatus according to this embodiment;

FIG. **5** is a flow chart illustrating the operation procedure for the APC (automatic gain control) at the time of the actual operation of the wireless communication apparatus according to this embodiment;

FIG. **6** is a block diagram showing part of the conventional wireless communication apparatus; and

FIG. **7** is a graph showing the relationship between a used channel and the passage loss of a transmission/reception branching filter in the conventional wireless communication apparatus.

MODE FOR CARRYING OUT THE INVENTION

Background to Contents of Embodiments of Disclosure

Before the description of a wireless communication apparatus and a transmission power control method according to an embodiment of the present disclosure, first, circumstances leading to the contents of this embodiment will be described referring to FIGS. **6** and **7**. FIG. **6** is a block diagram showing part of the conventional wireless communication apparatus (refer to Patent Document 1). FIG. **7** is a graph showing the relationship between a used channel and the passage loss of a transmission/reception branching filter in the conventional wireless communication apparatus (refer to Patent Document 1).

In the wireless communication apparatus shown in FIG. **6**, a transmission/reception branching filter **3** is connected via a directional coupler **2** to the output terminal of a power amplifier **1** for amplifying the electric power of a transmission signal modulated in a transmission section (not shown), and an antenna **4** is connected to one terminal of the transmission/reception branching filter **3** and a receiving section (not shown) is connected to the other terminal of the transmission/reception branching filter **3**.

The power amplifier **1** can change its output power depending on the control signal S**8** given to its power control terminal. The directional coupler **2** detects the output power of the power amplifier **1**. A detection diode **5** for detecting the output power of the power amplifier **1** as a DC voltage (a detection signal S**5**) is connected to the directional coupler **2**. The directional coupler **2** and the detection diode **5** operate as power detecting means for detecting the output power of the power amplifier **1** and outputting the detection signal S**5**.

An operational amplifier **6** compares the detection signal S**5** output from the detection diode **5** and a reference signal S**11** and changes the value of the detection signal S**5** so that the level difference between the two signals, obtained as the result of the comparison, becomes zero. Furthermore, the wireless communication apparatus shown in FIG. **6** is provided with a memory **9** in which output control data corresponding to the power level to be output from the output terminal of the antenna **4** is stored.

In other words, depending on the relationship between the used channel and the passage loss of the transmission/reception branching filter **3** shown in FIG. **7**, the output control data indicating the relationship between the used channel and the output power to be output from the output terminal of the antenna **4** is stored in the memory **9**. The passage loss of power occurs due to the directional coupler **2** and the transmission/reception branching filter **3** between the output terminal of the power amplifier **1** and the output terminal of the antenna **4**.

For example, the passage loss of the transmission/reception branching filter **3** shown in FIG. **7** is 2 dB at the used channels 0 to 100, 1 dB at the used channels 100 to 700, and 2 dB at the used channels 700 to 800. Hence, a correction value of 1 dB is required to be added at the used channels 0 to 100 and 700 to 800 to make the passage loss of the transmission/reception branching filter **3** constant. On the basis of the output control data, the wireless communication apparatus maintains the output power levels of all the used channels at the output terminal of the antenna **4** constant.

However, in the case that Patent Document 1 is applied to wireless communication in the millimeter wave band having a wide band width, the operating range of a detector (for example, a detection diode) for detecting the power of a high-frequency signal becomes insufficient; hence, the output voltage of the detector with respect to the input power thereof is not determined uniquely, and it becomes difficult to control the signal power of the high-frequency signal constant.

Moreover, although it is possible to virtually expand the operating range of the detector by mounting detectors having different operating ranges in parallel, variation among the respective detectors is large in wireless communication dealing with high-frequency signals (in particular, 60 GHz millimeter wave band wireless communication), and the detectors are required to be calibrated individually, which is not preferable.

Hence, in the following respective embodiments, examples of a wireless communication apparatus and a transmission power control method for making the EIRP of an antenna constant using a simple configuration even if variation occurs in antenna gain in wireless communication dealing with high-frequency signals are described.

Specific embodiments of the wireless communication apparatus and the transmission power control method according to the present disclosure will be described below referring to the drawings. The transmission power control method according to the present disclosure is carried out by the wireless communication apparatus according to the present disclosure. First, the configuration of the wireless communication apparatus will be described.

Configuration of the Wireless Communication Apparatus

FIG. **1** is a block diagram showing the configuration of a wireless communication apparatus **200** according to this embodiment. The wireless communication apparatus **200** shown in FIG. **1** includes a digital modulation signal generator **110**, DACs (Digital Analog Converters) **105***a* and **105***b*, variable gain amplifiers **104***a* and **104***b*, a quadrature modulation section **103**, a power amplifier **102**, a local oscillator **107**, a 90-degree phase shifter **106**, a coupler **101**, a transmission antenna **100**, a detector **108**, an ADC (Analog Digital Converter) **109**, a controller **111**, a first nonvolatile memory **112**, and a second nonvolatile memory **113**. The controller **111** includes a comparator **116**, a volatile memory **117**, a switch **118**, and a subtractor **119**.

The wireless communication apparatus **200** according to this embodiment generates a high-frequency signal having a millimeter wave band frequency, for example, approximately 60 GHz, and transmits the signal from the transmission antenna **100**. A tester **114** receives the high-frequency signal transmitted from the transmission antenna **100** using a receiving antenna **115**. Although differential signals are output from the digital modulation signal generator **110**, the DACs **105***a* and **105***b*, and the variable gain amplifiers **104***a* and **104***b* and then input to the quadrature modulation section **103** in FIG. **1**, a single end signal may be input.

The digital modulation signal generator **110** generates baseband signals (for example, testing tone signals) having the same amplitude and a phase difference of 90-degrees, outputs the in-phase signal (I signal) of the baseband signals to the DAC **105***a*, and outputs the quadrature signal (Q signal) of the baseband signals to the DAC **105***b*. The digital modulation signal generator **110** may generate the output levels of the baseband signals (for example, the testing tone signals) on the basis of the control signal S**110** output from the controller **111**.

The DAC **105***a* converts the digital in-phase signal output from the digital modulation signal generator **110** into an analog in-phase signal and outputs the signal to the variable gain amplifier **104***a*.

The DAC **105***b* converts the digital quadrature signal output from the digital modulation signal generator **110** into an analog quadrature signal and outputs the signal to the variable gain amplifier **104***b*.

The variable gain amplifier **104***a* changes its gain depending on the gain control signal S**104** output from the controller **111**, amplifies the in-phase signal output from the DAC **105***a* using the gain changed depending on the gain control signal S**104**, and outputs the amplified signal to the quadrature modulation section **103**. The indication of an arrow from the controller **111** to the variable gain amplifier **104***a* is omitted to simplify FIG. **1**.

The variable gain amplifier **104***b* changes its gain depending on the gain control signal S**104** output from the controller **111**, amplifies the quadrature signal output from the DAC **105***b* using the gain changed depending on the gain control signal S**104**, and outputs the amplified signal to the quadrature modulation section **103**.

The local oscillator **107** oscillates and generates a predetermined (for example, 60 GHz) local signal and outputs the signal to the 90-degree phase shifter **106**.

Using the local signal output from the local oscillator **107**, the 90-degree phase shifter **106** generates two local signals having the same amplitude and a phase difference of 90-degrees and outputs the signals to the quadrature modulation section **103**.

The quadrature modulation section **103** performs quadrature modulation using the baseband signals (the in-phase signal and the quadrature signal) output from the variable gain amplifiers **104***a* and **104***b* and the two local signals output from the 90-degree phase shifter **106**. The quadrature modulation section **103** generates a high-frequency signal (for example, a millimeter wave) by quadrature modulation and outputs the signal to the power amplifier **102**.

The power amplifier (PA) **102** amplifies the power of the high-frequency signal output from the quadrature modulation section **103** and outputs the amplified signal to the transmission antenna **100**. The high-frequency signal input to the transmission antenna **100** is transmitted and received by the receiving antenna **115** of the tester **114**.

The coupler **101** extracts part of the high-frequency signal amplified by the power amplifier **102** and outputs the part to the detector **108**. The power of the analog high-frequency signal extracted by the coupler **101** is lower than the power of the high-frequency signal amplified by the power amplifier **102** by 20 dB, for example.

The detector **108** detects the analog high-frequency signal extracted by the coupler **101** and outputs the signal to the ADC **109**. FIG. **2** is a graph showing the relationship between the input power [dBm] and the output voltage [V] in the case of the detector **108** having the minimum detection gain and in the case of the detector **108** having the maximum detection gain. In addition to the input power in the detector **108**, the transmission power (referred to as the EIRP [dBm] of the antenna) of the high-frequency signal transmitted from the transmission antenna **100** having a gain of 6 dBi is also shown on the horizontal axis of FIG. **2**.

The detection gain represents the ratio of the output voltage of the detector **108** to the input voltage corresponding to the input power. Since the detection gain of the detector **108** becomes different depending on the variation in a CMOS process, FIG. **2** shows the relationship between the input power and the output voltage in the case of the detector **108** having the maximum detection gain and in the case of the detector **108** having the minimum detection gain.

In FIG. **2**, the range in which the output voltage of the detector **108** is determined uniquely depending on the input power of the detector **108**, that is, the power of the high-frequency signal amplified by the power amplifier **102**, is the operating range (detection range) of the detector **108**. Hence, in the detector **108** shown in FIG. **2**, in the case that the output voltage of the detector **108** is in a range of 0.35 to 1.15 V, that is, in the area of the detection range, the detector **108** can be used for automatic gain control (see FIG. **4**) described later. On the other hand, in the area outside the detection range, the output voltage and the input power of the detector **108** are not in one-to-one correspondence, whereby it is difficult to use the area for the automatic gain control (see FIG. **4**).

For example, in the case of the detector **108** having the minimum detection gain, the range of the input power (EIRP) of the detector **108** from −17 dBm (+9 dBm) to −8 dBm (+18 dBm) is the detection range. Furthermore, for example, in the case of the detector **108** having the maximum detection gain, the range of the input power of the detector **108** from −24 dBm (+2 dBm) to −12 dBm (+14 dBm) is the effective detection range.

The ADC **109** converts the output of the detector **108**, that is, an analog output voltage, into a digital output voltage, and outputs the output voltage to the controller **111**.

The controller **111** outputs the control signal S**110** for generating the baseband signals to the digital modulation signal generator **110**. On the basis of the values (refer to the following description) stored in the first nonvolatile memory **112** and the second nonvolatile memory **113** and the output power ADCOUT corresponding to the digital output voltage output from the ADC **109**, the controller **111** generates the gain control signal S**104** for setting the gain of the variable gain amplifiers **104***a* and **104***b*, and outputs the gain to the variable gain amplifiers **104***a* and **104***b*.

The comparator **116** compares the value TXADC_RDATA stored in the first nonvolatile memory **112** with the power ADCOUT corresponding to the digital output voltage output from the ADC **109**. The value TXADC_RDATA is the desired value of the EIRP of the high-frequency signal to be transmitted from the wireless communication apparatus **200** and is written by the tester **114**. Depending on the result of the comparison of the value TXADC_RDATA stored in the first nonvolatile memory **112** with the power ADCOUT corresponding to the digital output voltage output from the ADC **109**, the comparator **116** increases the gain TXGAIN stored in the volatile memory **117**.

The volatile memory **117** stores the gain TXGAIN of the variable gain amplifiers **104***a* and **104***b*. The gain TXGAIN stored in the volatile memory **117** is input to the switch **118** and the subtractor **119**.

The switch **118** selects the gain TXGAIN stored in the volatile memory **117** or the output (the result of subtraction) of the subtractor **119** and outputs the gain or the output as the gain control signal S**104** to the variable gain amplifiers **104***a* and **104***b*.

The subtractor **119** subtracts the offset value P_OFFSET stored in the second nonvolatile memory **113** from the gain TXGAIN stored in the volatile memory **117** and outputs the obtained value to the switch **118**.

The first nonvolatile memory **112** stores the target value TXADC_RDATA of the EIRP of the high-frequency signal transmitted from the transmission antenna **100**. A nonvolatile memory produced using, for example, the eFUSE production

technology, is used as the first nonvolatile memory **112**. As a result, the production cost of the first nonvolatile memory **112** can be reduced.

In the case that, for example, the output voltage of the detector **108** is the lower limit value (for example, 0.35 V, see FIG. **2**) of the detection range and that the EIRP is larger than the upper limit value in the desired range of the transmission power, the second nonvolatile memory **113** stores the offset value P_OFFSET for reducing the EIRP by a predetermined amount. The offset value P_OFFSET is written using the tester **114**. A nonvolatile memory produced using, for example, the eFUSE production technology, is used as the second nonvolatile memory **113**. As a result, the production cost of the second nonvolatile memory **113** can be reduced.

The receiving antenna **115** receives the high-frequency signal transmitted from the transmission antenna **100** and outputs the signal to the tester **114**.

The tester **114** holds the information about the desired range of the transmission power of the high-frequency signal to be transmitted from the wireless communication apparatus **200**. In the following description, it is assumed that, for example, the lower limit value in the desired range of the transmission power is 6.5 dBm and that the upper limit value thereof is 9.5 dBm. The tester **114** measures the EIRP of the high-frequency signal output from the receiving antenna **115** and judges whether the EIRP is in the desired range of the transmission power. Depending on the result of the judgment, the tester **114** renews the contents of the first and second nonvolatile memories **112** and **113**.

Operation of the Tester **114** for Writing Data in the Respective Nonvolatile Memories

Next, the operation of the tester **114** for writing data in the first and second nonvolatile memories **112** and **113** depending on the EIRP of the high-frequency signal transmitted from the wireless communication apparatus **200** will be described referring to FIGS. **3** and **4**. FIG. **3** is a flow chart illustrating the operation procedure for writing data in the first and second nonvolatile memories **112** and **113** of the wireless communication apparatus **200** according to this embodiment. FIG. **4** is a flow chart illustrating the operation procedure of the APC (automatic gain control) of the wireless communication apparatus **200** according to this embodiment. The operations of the respective flow charts shown in FIGS. **3** and **4** will be carried out, for example, at the time of the shipment inspection of the wireless communication apparatus **200**.

In FIG. **3**, first, the tester **114** sets a variable TXADC_ADJ and the offset value P_OFFSET to 0 (zero) and sets the target value TXADC_RDATA of the EIRP to its initial value (at S**11**). The initial value of the target value TXADC_RDATA of the EIRP is an appropriate predetermined value prescribed beforehand by actual measurement or simulation.

After step S**11**, the wireless communication apparatus **200** carries out the APC (automatic gain control) (at S**12**). The APC in the wireless communication apparatus **200** will be herein described in detail referring to FIG. **4**.

In FIG. **4**, the controller **111** switches the input of the switch **118** to the output of the volatile memory **117** (at S**12-1**). The controller **111** reads the initial value of the gain of the variable gain amplifiers **104***a* and **104***b*, that is, the minimum gain TXGAIN, from the volatile memory **117**, generates the gain control signal S**104** for setting the gain of the variable gain amplifiers **104***a* and **104***b*, and outputs the signal to the variable gain amplifiers **104***a* and **104***b*. The variable gain amplifiers **104***a* and **104***b* set the gain TXGAIN of the variable gain amplifiers **104***a* and **104***b* to the initial value depending on the gain control signal S**104** (at S**12-2**).

Furthermore, the controller **111** outputs the control signal S**110** for generating the baseband signals to the digital modulation signal generator **110**. On the basis of the control signal S**110** output from the controller **111**, the digital modulation signal generator **110** generates the baseband signals (for example, the testing tone signals), outputs the in-phase signal (I signal) of the baseband signals to the DAC **105***a*, and outputs the quadrature signal (Q signal) of the baseband signals to the DAC **105***b* (at S**12-3**).

The DAC **105***a* converts the digital in-phase signal output from the digital modulation signal generator **110** into the analog in-phase signal and outputs the signal to the variable gain amplifier **104***a*. The DAC **105***b* converts the digital quadrature signal output from the digital modulation signal generator **110** into the analog quadrature signal and outputs the signal to the variable gain amplifier **104***b*.

The variable gain amplifier **104***a* amplifies the in-phase signal output from the DAC **105***a* using the gain changed depending on the gain control signal S**104**, and outputs the amplified signal to the quadrature modulation section **103** (at S**12-4**). The variable gain amplifier **104***b* amplifies the quadrature signal output from the DAC **105***b* using the gain changed depending on the gain control signal S**104**, and outputs the amplified signal to the quadrature modulation section **103** (at S**12-4**).

The quadrature modulation section **103** performs quadrature modulation using the in-phase signal and the quadrature signal of the baseband signals output from the variable gain amplifiers **104***a* and **104***b* and the two local signals output from the 90-degree phase shifter **106** (at S**12-5**). The quadrature modulation section **103** generates a high-frequency signal (for example, a millimeter wave) by quadrature modulation and outputs the signal to the power amplifier **102**.

The power amplifier **102** amplifies the power of the high-frequency signal output from the quadrature modulation section **103** and outputs the amplified signal to the transmission antenna **100** (at S**12-6**). The coupler **101** extracts part of the high-frequency signal amplified by the power amplifier **102** and outputs the part to the detector **108**. The detector **108** detects the analog high-frequency signal extracted by the coupler **101** and outputs the signal to the ADC **109** (at S**12-7**). The ADC **109** converts the output of the detector **108**, that is, an analog output voltage, into a digital output voltage, and outputs the output voltage to the controller **111** (at S**12-7**).

The controller **111** compares the initial value of the target value TXADC_RDATA of the EIRP set at step S**11** with the power ADCOUT corresponding to the digital output voltage output from the ADC **109** (at S**12-8**). Upon judging that the power ADCOUT corresponding to the digital output voltage is not less than the initial value of the target value TXADC_RDATA of the EIRP (NO at S**12-8**), the controller **111** determines the gain TXGAIN of the variable gain amplifiers **104***a* and **104***b* set at step S**12-2** (at S**12-9**). Consequently, the APC in the wireless communication apparatus **200** is completed.

On the other hand, upon judging that the power ADCOUT corresponding to the digital output voltage is less than the initial value of the target value TXADC_RDATA of the EIRP (YES at S**12-8**), the controller **111** increases the gain TXGAIN of the variable gain amplifiers **104***a* and **104***b* set at step S**12-2** by 1 dB (at S**12-10**). After step S**12-10**, the controller **111** outputs the control signal S**110** for generating the baseband signals to the digital modulation signal generator **110**. In other words, the operation from step S**12-3** to step S**12-10** is repeated until the power ADCOUT corresponding

to the digital output voltage becomes not less than the initial value of the target value TXADC_RDATA of the EIRP.

After the APC shown in FIG. **4**, the tester **114** measures the EIRP of the high-frequency signal transmitted from the transmission antenna **100** (at S**13**). The tester **114** judges whether the EIRP measured at step S**13** is in the desired range of the transmission power (at S**14**).

More specifically, the tester **114** judges whether the EIRP measured at step S**13** is not less than the upper limit value (for example, 9.5 dBm) in the desired range of the transmission power (at S**14**). Upon judging that the EIRP is not less than the upper limit value (for example, 9.5 dBm) in the desired range of the transmission power (YES at S**14**), the tester **114** writes INT(EIRP-**8**), that is, the integer value of (EIRP-**8**), as the offset value P_OFFSET in the second nonvolatile memory **113** (at S**15** and S**16**). It is noted that 8 dBm is an example of the center value (desired value) of the desired range of the transmission power.

Upon judging that the EIRP is less than the upper limit value (for example, 9.5 dBm) in the desired range of the transmission power (NO at S**14**), the tester **114** judges whether the EIRP is not less than the lower limit value (for example, 6.5 dBm) in the desired range of the transmission power (at S**17**).

Upon judging that the EIRP is not less than the lower limit value (for example, 6.5 dBm) in the desired range of the transmission power (YES at S**17**), the tester **114** does not change the initial value of the target value TXADC_RDATA of the EIRP set at step S**11**, and the operation shown in FIG. **3** is completed.

On the other hand, upon judging that the EIRP is less than the lower limit value (for example, 6.5 dBm) in the desired range of the transmission power (NO at S**17**), the tester **114** renews the variable TXADC_ADJ set to 0 (zero) at step S**11** to (**8**-EIRP) (at S**18**). Furthermore, using the target value TXADC_RDATA of the EIRP having been set to the initial value at step S**11**, the tester **114** adds the initial value of the target value TXADC_RDATA of the EIRP to the variable TXADC_ADJ renewed at step S**18** (at S**19**). The tester **114** writes the target value TXADC_RDATA of the EIRP, obtained as the result of the addition, in the first nonvolatile memory **112** (at S**16**). Hence, the operation shown in FIG. **3** is completed.

Transmission Power Control Method in the Wireless Communication Apparatus **200**

Next, the transmission power control method in the wireless communication apparatus **200** according to this embodiment will be described referring to FIG. **5**. FIG. **5** is a flow chart illustrating the operation procedure for the APC (automatic gain control) at the time of the actual operation of the wireless communication apparatus **200** according to this embodiment.

In FIG. **5**, the controller **111** switches the input of the switch **118** to the output of the volatile memory **117** (at S**21**). The controller **111** reads the initial value of the gain of the variable gain amplifiers **104***a* and **104***b*, that is, the minimum gain TXGAIN, from the volatile memory **117**, generates the gain control signal S**104** for setting the gain of the variable gain amplifiers **104***a* and **104***b*, and outputs the signal to the variable gain amplifiers **104***a* and **104***b*. The variable gain amplifiers **104***a* and **104***b* set the gain TXGAIN of the variable gain amplifiers **104***a* and **104***b* to the initial value depending on the gain control signal S**104** (at S**22**).

Furthermore, the controller **111** outputs the control signal S**110** for generating the baseband signals to the digital modulation signal generator **110**. On the basis of the control signal S**110** output from the controller **111**, the] digital modulation signal generator **110** generates the baseband signals (for example, the testing tone signals), outputs the in-phase signal (I signal) of the baseband signals to the DAC **105***a*, and outputs the quadrature signal (Q signal) to the DAC **105***b* (at S**23**).

The DAC **105***a* converts the digital in-phase signal output from the digital modulation signal generator **110** into the analog in-phase signal and outputs the signal to the variable gain amplifier **104***a*. The DAC **105***b* converts the digital quadrature signal output from the digital modulation signal generator **110** into the analog quadrature signal and outputs the signal to the variable gain amplifier **104***b*.

The variable gain amplifier **104***a* amplifies the in-phase signal output from the DAC **105***a* using the gain changed depending on the gain control signal S**104**, and outputs the amplified signal to the quadrature modulation section **103**. The variable gain amplifier **104***b* amplifies the quadrature signal output from the DAC **105***b* using the gain changed depending on the gain control signal S**104**, and outputs the amplified signal to the quadrature modulation section **103**.

The quadrature modulation section **103** performs quadrature modulation using the in-phase signal and the quadrature signal of the baseband signals output from the variable gain amplifiers **104***a* and **104***b* and the two local signals output from the 90-degree phase shifter **106**. The quadrature modulation section **103** generates a high-frequency signal (for example, a millimeter wave) by quadrature modulation and outputs the signal to the power amplifier **102**.

The power amplifier **102** amplifies the power of the high-frequency signal output from the quadrature modulation section **103** and outputs the amplified signal to the transmission antenna **100**. The coupler **101** extracts part of the high-frequency signal amplified by the power amplifier **102** and outputs the part to the detector **108**. The detector **108** detects the analog high-frequency signal extracted by the coupler **101** and outputs the signal to the ADC **109** (at S**24**). The ADC **109** converts the output of the detector **108**, that is, an analog output voltage, into a digital output voltage and outputs the output voltage to the controller **111** (at S**24**).

The controller **111** compares the target value TXADC_RDATA of the EIRP written in the first nonvolatile memory **112**, for example, at the time of the shipment inspection, with the power ADCOUT corresponding to the digital output voltage output from the ADC **109** at step S**24** (at S**25**). Upon judging that the power ADCOUT corresponding to the digital output voltage is less than the target value TXADC_RDATA of the EIRP (NO at S**25**), the controller **111** increases the gain TXGAIN of the variable gain amplifiers **104***a* and **104***b* stored in the volatile memory **117** by 1 dB (at S**26**). After step S**2**, the operation of the wireless communication apparatus **200** returns to step S**24**.

Upon judging that the power ADCOUT corresponding to the digital output voltage output from the ADC **109** at step S**24** is not less than the target value TXADC_RDATA of the EIRP (YES at S**25**), the controller **111** reads the offset value P_OFFSET written by the tester **114** at the time of the shipment inspection from the second nonvolatile memory **113**.

Moreover, the controller **111** subtracts the offset value P_OFFSET from the gain of the variable gain amplifiers **104***a* and **104***b* stored in the volatile memory **117** (at S**27**) and switches the input of the switch **118** from the output of the volatile memory **117** to the output of the subtractor **119** (at S**28**). Hence, the controller **111** generates the gain control signal S**104** for setting the gain subjected to the subtraction at the subtractor **119** and outputs the signal to the variable gain

amplifiers **104***a* and **104***b*. The variable gain amplifiers **104***a* and **104***b* can set the gain of the respective variable gain amplifiers **104***a* and **104***b* depending on the gain control signal S**104**.

Consequently, in the wireless communication apparatus **200** according to this embodiment, for example, at the time of the shipment inspection, the target value TXADC_RDATA of the EIRP of the high-frequency signal is set to its initial value, and the gain of the variable gain amplifiers **104***a* and **104***b* is determined by the APC (automatic gain control). Furthermore, in the wireless communication apparatus **200**, depending on whether the EIRP of the high-frequency signal, obtained by using the determined gain, is in the desired range of the transmission power, the target value TXADC_RDATA of the EIRP and the offset value P_OFFSET for decreasing the EIRP by the predetermined amount are calculated and written in the first and second nonvolatile memories **112** and **113**.

Furthermore, in the wireless communication apparatus **200**, for example, at the time of its actual operation, the gain of the variable gain amplifiers **104***a* and **104***b* is adjusted so that the output power ADCOUT corresponding to the output voltage of the ADC **109** becomes the target value TXADC_RDATA of the EIRP of the high-frequency signal written in the first nonvolatile memory **112**. Moreover, in the wireless communication apparatus **200**, in the case that the output power ADCOUT corresponding to the output voltage of the ADC **109** is larger than the target value TXADC_RDATA of the EIRP, the gain of the variable gain amplifiers **104***a* and **104***b* stored in the volatile memory **117** is subtracted by the offset value P_OFFSET stored in the second nonvolatile memory **113**.

Consequently, in the wireless communication apparatus **200** according to this embodiment, for example, at the time of the shipment inspection, the gain of the variable gain amplifiers **104***a* and **104***b* can be set so that the measurement result of the EIRP of the high-frequency signal becomes the target value TXADC_RDATA in the APC (automatic gain control). In the wireless communication apparatus **200**, in the case that the EIRP of the high-frequency signal is not less than the upper limit value in the desired range of the transmission power, the offset value P_OFFSET for decreasing the EIRP of the high-frequency signal by the predetermined amount can be calculated. Moreover, in the wireless communication apparatus **200**, in the case that the EIRP of the high-frequency signal is less than the lower limit value in the desired range of the transmission power, the target value of the EIRP of the high-frequency signal can be adjusted.

What's more, in the case that the output voltage of the detector **108** having the minimum detection gain at the time of the shipment inspection is 0.35 V and that the EIRP of the high-frequency signal is more than 11 dBm (for example, 12 dBm), the range is outside the detection range of the detector **108** (see FIG. **2**); hence, the output voltage with respect to the input power at the detector **108** is not determined uniquely, and it is difficult to decrease the EIRP of the high-frequency signal.

In the wireless communication apparatus **200**, even in the case that the output voltage of the detector **108** having the minimum detection gain at the time of the shipment inspection is 0.35 V and that the EIRP of the high-frequency signal is more than 11 dBm, in the case that the target value TXADC_RDATA of the EIRP of the high-frequency signal is set to 8 dBm, the offset value P_OFFSET can be subtracted from the gain of the variable gain amplifiers **104***a* and **104***b* at the time of the actual operation; hence, the transmission power of the high-frequency signal can be decreased from 11 dBm by 3 dBm, for example.

Still further, in the wireless communication apparatus **200**, for example, at the time of the shipment inspection, the target value TXADC_RDATA of the EIRP of the high-frequency signal is set depending on the EIRP of the high-frequency signal transmitted from the transmission antenna **100**; hence, even in the case that the gain of the transmission antenna **100** varies, the EIRP of the high-frequency signal can be made constant. Consequently, in the wireless communication apparatus **200**, in the case of wireless communication dealing with high-frequency signals, even if the gain of the antenna varies, the EIRP of the antenna can be made constant.

Although various embodiments have been described above referring to the drawings, it is needless to say that the present disclosure is not limited to the embodiments. It is obvious that those skilled in the art can devise various alterations or modifications within the scope set forth in the claims, and it is understood that these belong to the technical scope of the present disclosure as a matter of course.

The value in the desired range of the transmission power used in the above-mentioned embodiments is used as an example and does not restrict the desired range of the transmission power.

In addition, in the wireless communication apparatus **200**, a comparator may be used instead of the ADC **109**.

Furthermore, although the offset value P_OFFSET is used to decrease the gain of the variable gain amplifiers **104***a* and **104***b* in the above-mentioned embodiments, the offset value P_OFFSET may be used to increase the gain of the variable gain amplifiers **104***a* and **104***b*.

The present application is based on Japanese Patent Application (JP-2013-23451) filed on Feb. 8, 2013, the contents of which are hereby incorporated by reference.

INDUSTRIAL APPLICABILITY

The present disclosure is useful as a wireless communication apparatus and a transmission power control method for making the EIRP of an antenna constant even if the gain of the antenna varies in wireless communication dealing with high-frequency signals.

DESCRIPTION OF REFERENCE NUMERALS AND SIGNS

100 transmission antenna
101 coupler
102 power amplifier
103 quadrature modulation section
104*a*, **104***b* variable gain amplifier
105*a*, **105***b* DAC
106 90-degree phase shifter
107 local oscillator
108 detector
109 ADC
110 digital modulation signal generator
111 controller
112, **113** nonvolatile memory
114 tester
115 receiving antenna
116 comparator
117 volatile memory
118 switch
119 subtractor
200 wireless communication apparatus

What is claimed is:

1. A wireless communication apparatus comprising:

a variable gain amplifier that amplifies a baseband signal;

a quadrature modulator that quadrature-modulates the amplified baseband signal to generate a high-frequency signal;

a power amplifier that amplifies the generated high-frequency signal;

a transmitting antenna that transmits the amplified high-frequency signal;

a detector that generates a detection signal obtained by detecting the amplified high-frequency signal;

a receiving antenna that receives the transmitted amplified high-frequency signal by the transmitting antenna and outputs as a received signal;

a first nonvolatile memory that stores a value of a desired transmission power of the high-frequency signal to be transmitted from the transmitting antenna, the value being set based on the received signal;

a second nonvolatile memory that stores a gain adjustment value for adjusting a gain of the variable gain amplifier in the case that the detection signal is equal to or greater than the value of the desired transmission power; and

a controller that increases the gain of the variable gain amplifier in the case that the detection signal is smaller than the value of the desired transmission power, and subtracts the gain adjustment value from the gain of the variable gain amplifier in the case that the detection signal is equal to or greater than the value of the desired transmission power.

2. The wireless communication apparatus according to claim 1, wherein the controller adjusts the gain of the variable gain amplifier so that the output of the detector is equal to the value of the desired transmission power stored in the first nonvolatile memory.

3. A transmission power control method for use in a wireless communication apparatus for transmitting a high-frequency signal amplified by a variable gain amplifier from an antenna and in a tester for testing a transmission power of the high-frequency signal transmitted from the antenna,

wherein the wireless communication apparatus has a first nonvolatile memory and a second nonvolatile memory;

wherein the tester stores a desired range of the transmission power of the high-frequency signal to be transmitted from the antenna;

wherein in the case that the transmission power of the high-frequency signal transmitted from the antenna after the gain of variable gain amplifier has been adjusted is smaller than the desired range of the transmission power, the tester writes an adjustment value for increasing the transmission power of the high-frequency signal in the first nonvolatile memory;

wherein in the case that the transmission power of the high-frequency signal transmitted from the antenna after the gain of variable gain amplifier has been adjusted is equal to or greater than the desired range of the transmission power, the tester writes an adjustment value for decreasing the transmission power of the high-frequency signal in the second nonvolatile memory; and

wherein in the case that the transmission power of the high-frequency signal transmitted from the antenna after the gain of the variable gain amplifiers has been adjusted is in the desired range of the transmission power, the tester does not write in the first nonvolatile memory and in the second nonvolatile memory.

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